

H-II Transfer Vehicle (HTV) and the Operations Concept for Extravehicular Activity (EVA) Hardware

Cinda Chullen¹ and Elizabeth Blome²
NASA, Houston Texas, 77058

and

Sakashita Tetsuya³
Japan Aerospace Exploration Agency, Tsukuba, Japan

With the retirement of the Space Shuttle fleet imminent in 2011, a new operations concept will become reality to meet the transportation challenges of the International Space Station (ISS). The planning associated with the retirement of the Space Shuttle has been underway since the announcement in 2004¹. Since then, several companies and government entities have had to look for innovative low-cost commercial orbital transportation systems to continue to achieve the objectives of ISS delivery requirements. Several options have been assessed and appear ready to meet the large and demanding delivery requirements of the ISS. Options that have been identified that can facilitate the challenge include the Russian Federal Space Agency's Soyuz and Progress spacecraft, European Space Agency's Automated Transfer Vehicle (ATV), and the Japan Aerospace Exploration Agency's (JAXA's) H-II Transfer Vehicle (HTV).² The newest of these options is the JAXA's HTV. This paper focuses on the HTV, mission architecture and operations concept for Extra-Vehicular Activities (EVA) hardware, the associated launch system, and details of the launch operations approach.

Nomenclature

<i>ATV</i>	= Automated Transport Vehicle
<i>A/L</i>	= Airlock
<i>AM</i>	= Avionics Module
<i>CCA</i>	= Communication Cap Assembly
<i>CRS</i>	= Cargo Resupply Service
<i>CO₂</i>	= carbon dioxide
<i>CWS</i>	= Caution & Warning System
<i>DCM</i>	= Display and Control Module
<i>EP</i>	= Exposed Pallet
<i>EVA</i>	= Extravehicular Activity
<i>EMU</i>	= Extravehicular Mobility Unit
<i>GPS</i>	= Global Positioning System
<i>GTO</i>	= Geostationary Transfer Orbit
<i>HRR</i>	= HTV Resupply Racks
<i>HTV</i>	= H-II Transfer Vehicle
<i>HUT</i>	= Hard-Upper Torso
<i>IP</i>	= International Partner
<i>ISS</i>	= International Space Station
<i>ISSP</i>	= International Space Station Program

¹ Project Engineer, Space Suit and Crew Survival Systems Branch, Crew and Thermal Systems Division, 2101 NASA Parkway, Houston, TX 77058/EC5.

² Launch Package Manager, Cargo Integration, Mission Integration & Operations Office, International Space Station Program, 2001 NASA Parkway, Houston, TX 77058/OC.

³ Engineer, HTV project team, Tsukuba Space Center, 2-1-1 Sengen, Tsukuba, Ibaraki, Japan 3058505, AIAA member.

<i>JAXA</i>	= Aerospace Exploration Agency
<i>JSC</i>	= Johnson Space Center
<i>LCVG</i>	= Liquid Cooling and Ventilation Garment
<i>LEO</i>	= Low Earth Orbit
<i>LTA</i>	= Lower Torso Assembly
<i>MEGA</i>	= Maximized EVA Ground Activity
<i>MHI</i>	= Mitsubishi Heavy Industries
<i>NASA</i>	= National Aeronautics and Space Administration
<i>NASDA</i>	= National Space Development Agency of Japan
<i>PGT</i>	= Pistol Grip Tool
<i>PLC</i>	= Pressurized Logistic Carrier
<i>PLSS</i>	= Portable Life-Support System
<i>RCS</i>	= Reaction Control System
<i>SOP</i>	= Secondary Oxygen Pack
<i>SSP</i>	= Space Shuttle Program
<i>STS</i>	= Space Transportation System
<i>TDRS</i>	= Tracking and Data Relay Satellite System
<i>ULC</i>	= Unpressurized Logistics Carrier
<i>US</i>	= United States
<i>USOS</i>	= United States On-orbit Segment

I. Introduction

National Aeronautics and Space Administration (NASA) has been planning for the eventual completion of the Space Shuttle Program (SSP) mission manifest as part of former President Bush's *Vision for Space Exploration, 2004*. Now with the retirement of the Space Shuttle imminent and the extended life of the ISS to 2015 and possibly beyond, the ISS program requires other means to reliably deliver crew and cargo.³

The existing international governmental options for cargo delivery include the Russian Federal Space Agency's Soyuz and Progress spacecraft, the European Space Agency's Automated Transfer Vehicle (ATV), and Japan Aerospace Exploration Agency's (JAXA's) H-II Transfer Vehicle (HTV).^{1,2} While under development, the ISS Program (ISSP) designated only two unmanned cargo vehicles (ATV and the HTV) to resupply of the United States On-orbit Segment (USOS). They both are planned to provide the additional upmass capability to ISS to help meet its annual resupply requirements.⁶ However, at the end of 2011 the Russian Federal Space Agency will no longer provide cargo upmass on the Progress spacecraft, thereby necessitating the U.S. commercial cargo delivery systems.

Servicing ISS is more challenging than existing commercial space transportation capabilities can provide. Therefore, NASA initiated a commercialization project to stimulate United States commercial enterprises in space. This project was undertaken to provide an alternative to flying cargo to the ISS solely on government and International Partner (IP) operated vehicles. The goal is to open new markets and challenge private industry to provide commercial delivery of crew and cargo to the ISS.¹

As of 2011, efforts for commercialization are still progressing with two companies still developing new commercial cargo delivery systems. However, it does not appear that a new commercial system will materialize, be fully qualified, and become operational prior to the retirement of the Space Shuttle program.²

Due to the space shuttle retirement alternate launch vehicles are required for all hardware providers, including the EVA community. Extra-Vehicular Activities (EVA) hardware is an example of the need for "pressurized" resupply. The HTV is currently the targeted vehicle for a significant portion of EVA hardware due to its pressurized module capability.⁷ This paper focuses on the HTV, mission architecture and operations concept, the associated launch system, and details of the launch operations approach.

II. Background

The expected retirement of the Space Shuttle by 2011 will pose a significant challenge to Extra-Vehicular Activities (EVA) on-board the International Space Station (ISS). The EVA hardware currently used to assemble and maintain the ISS was designed assuming that it would be returned to Earth on the Space Shuttle for ground processing, refurbishment, or if necessary for failure investigation. A new concept of operations had to be developed to enable EVA community to realize an alternate approach to the Space Shuttle. After many months of deliberating, the EVA community, management, and the ISS program, and an EVA 2010 focus team agreed to the recommendation that Extra-vehicular Mobility Unit (EMU) EVA capability, being based on ground turnaround processing and refurbishment utilizing the Space Shuttle as the transfer vehicle, must switch to a longer-term

solution of on-orbit maintenance and disposable mentality. The focus then shifted into achieving a capability of launching on alternate vehicles, extending the maintenance interval of hardware to create long-duration “MEGA” EMUs, enhancement of on-orbit maintenance activities, enhancements in processing techniques, and documentation updates. MEGA” means Maximized EVA Ground Activity. An EVA 2010 Team was formulated to carry out the necessary projects and effort that would have to be undertaken to ensure that the EVA systems would be safe and available for ISS until 2016.⁷

III. EVA Systems Hardware

The EVA systems needed to ensure safe performance of ISS EVAs until 2016, and possibly beyond to 2020 includes the EMU and EMU components, Airlock (A/L) Systems, EVA tools and crew aids along with associated support equipment and consumables.⁷ EMU hardware targeted for the HTV includes the Portable Life-Support System (PLSS) and or PLSS/Secondary Oxygen Pack (SOP), launched in a fixture to protect it from vehicle vibrations & launch loads. The Display and Control Module (DCM), SOP, Hard-Upper Torso (HUT), etc can be “soft-stowed” in bags. Fig. 1 shows the EMU hardware that will need to be launched on the HTV. The EMU hardware will need to be re-assembled and checked out on-orbit. EMUs are currently launched as an integrated unit in the Shuttle. The EVA systems are described below with the need for their capability defined.

A. EMU

The EMU is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the crewmember to perform Extravehicular Activity (EVA) in Earth orbit. The EMU is designed to accommodate EVAs from both on-board the ISS and Space Shuttle Orbiter airlocks for a planned EVA duration of 6.5 hrs, although the EMU can support EVAs longer if necessary. The EMU consists of the spacesuit assembly and the Life-Support System.⁸ The spacesuit assembly consists of a HUT, Lower Torso Assembly (LTA), gloves, Helmet/Visor Assembly, the Liquid Cooling and Ventilation Garment (LCVG), and the Communication Cap Assembly (CCA). The Life Support System consists of a PLSS, a SOP, EMU battery, a carbon dioxide (CO₂) removal cartridge, radio & telemetry system, a Caution & Warning System (CWS), and the DCM.

B. EVA Tools & Crew Aids

There are over 350 different EVA tools and crew aids. These tool designs and are available for use by the EVA crewmember, depending on the task. In general EVA tools are categorized as large tools, small tools, with the Pistol Grip Tool (PGT) considered separate from the small-tools given its complexity. During a typical EVA, the crewmember may have up to a dozen small tools attached to them on the EMU and another dozen in a crew lock bag.⁷

C. A/L Systems

The ISS A/L module for the EMUs is located on the starboard side of Node 1. The A/L provides the capability to service, maintain, don, doff, and store the EMUs to allow ISS crews, in EMUs, access to the exterior of ISS to

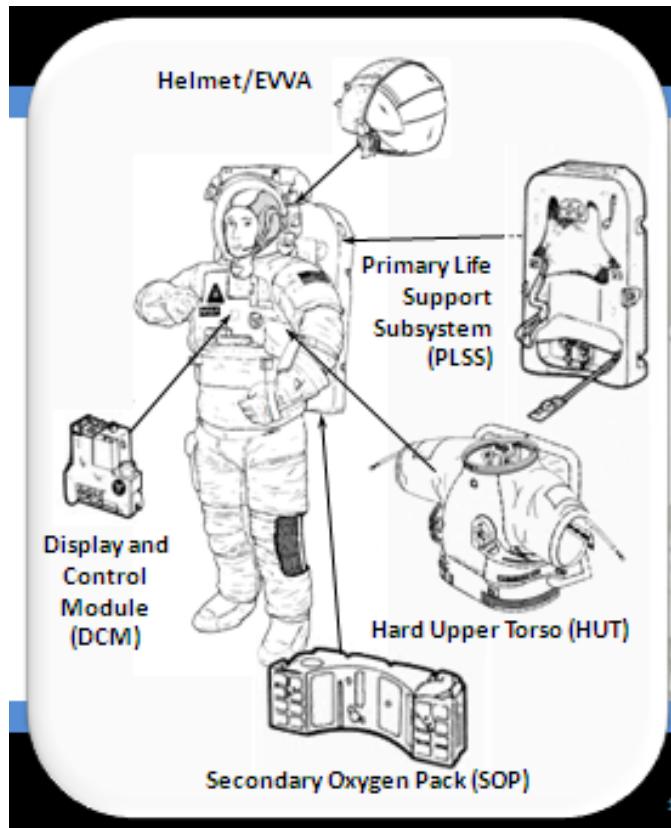


Figure 1. EMU Hardware on HTV

perform assembly & maintenance tasks. It has the capability to service EVA tools and other EVA ancillary equipment. It was launched early in the ISS assembly sequence on Space Transportation System (STS)-104/7A in July 2001 and remains in operation. The A/L does not have the capability to service the Russian Orlan spacesuit. The A/L for the Orlan resides on the Russian Segment. The Orlan and the associated A/L module are not considered in this paper for resupply to ISS.⁷

IV. EVA Systems Launching on International Partner Vehicles

The ultimate decision resides with the ISSP to launch hardware to the ISS post-Shuttle retirement. It is believed that the vehicles (namely the proven Soyuz and Progress vehicles to the HTV and the ATV under consideration by ISS would allow for continued EVA activity on the ISS.⁷ However, early on in the EMU EVA assessment, the decision was made by the ISSP to use the JAXA HTV as the prime vehicle for launching EVA hardware, especially the EMU PLSS/SOP launch fixture. However, after the EVA 2010 Team held a series of technical interface meetings with representatives of JAXA to better understand the launch environment of the HTV, it was realized that given the stowage limitations of the HTV and the logistics requirements of the EMU, that major components of the spacesuit would have to be launched individually on the HTV. This meant that the components would have to be assembled on-orbit by the ISS crew and that the PLSS/SOP would have to be isolated from the vibration and loads environment for the JAXA H-IIB launch vehicle. This was a dramatic shift in operational philosophy from Space Shuttle program where the PLSS/SOP & DCM are launched fully integrated into the EMU HUT. The crew would have to assemble the EMUs on-orbit and perform an EVA checkout which is currently done on the ground by trained technicians. Crew training for ISS Expedition crews would have to be enhanced, long-standing procedures modified, and high-fidelity mockups built to accommodate this shift in operational philosophy.

Most of the EVA EMU hardware would be launched in bags as soft-stowed. However, due to the critical nature of the PLSS, it was determined that a special launch fixture would need to be design and fabricated to isolate the PLSS from the acceleration loads not to exceed 12.5g's.⁷

This paper does not address EVA hardware launching on commercial vehicles (e.g. Cargo Resupply Service (CRS)).

V. EVA ISS Ops Concept Post-Shuttle

In the 1970's, the EVA systems hardware was designed to support short-duration Space Shuttle missions. The hardware was designed to fly on a shuttle mission, perform 1-3 EVAs, then return to earth for refurbishment and checkout by ground personnel before being re-flown. This concept of operations was significantly different than those on previous NASA missions such as Apollo and Skylab. In pre-Shuttle missions, due to the nature of the mission and limited cargo return capability, much of the EVA hardware, including the PLSS, was discarded either on the lunar surface or left on-board Skylab. The Space Shuttle provided the capability to return EVA systems hardware for refurbishment, repair, and failure investigation. Mission designers took advantage of this capability in designing the EMU and associated hardware. Therefore, the Space Shuttle EMU has operated on orbit for EVAs and returned home to be maintained on the ground.

Shortly after the decision to retire the Space Shuttle was made in 2004, it was realized that the entire EVA operations concept for providing EMU EVAs on ISS would have to significantly change. Without a vehicle to provide return capability, EVA hardware would have to become disposable. Therefore, a new operations concept was generated. The current post-Shuttle operations concept for EVA hardware is shown in Fig. 2. The goals are to

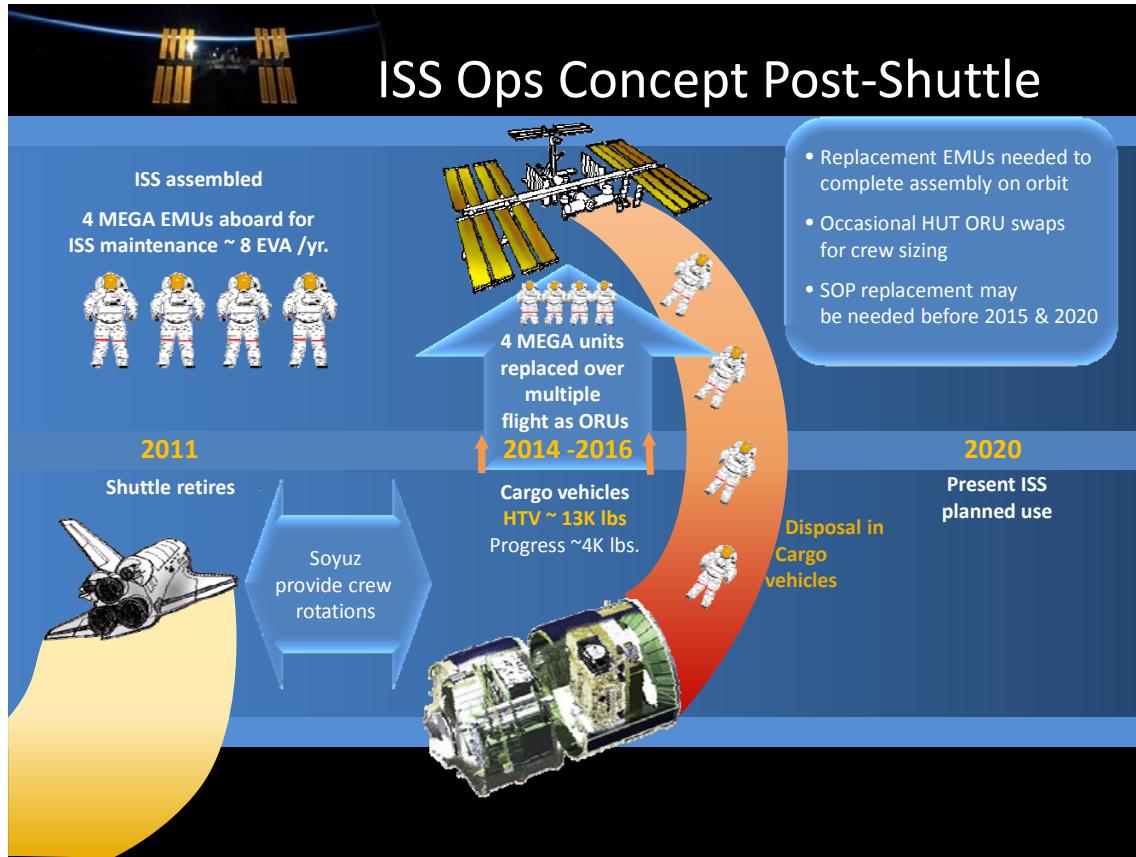


Figure 2. ISS Operations Concept Post-Shuttle for EVA Systems hardware

maintain 4 “MEGA” EMUs on orbit in order to accomplish up to 8 EVAs annually if needed. The designation of “MEGA” really means that these EMUs will have received special ground processing that qualifies these particular units to go longer between maintenance cycles. The EMUs currently have a 3-year maintenance cycle. After the special ground processing is applied, the units can then qualify for a total of a 6- year maintenance cycle. Each of these special processed EMUs, now referred to as “MEGA” units will retain the certification for 25 EVAs and their components remain in relative the same configuration except for a few minor enhancements.

The EMU components such as the PLSS would be transported on the HTV after the Shuttle retires. For example the PLSS hardware would continue to be transported on the HTV until all MEGA units are depleted. The current estimate is that there would be at least one HTV flight per year. Additionally the on-orbit life of EVA hardware would have to be extended as much as possible to minimize upmass requirements, and procedures would have to be developed to allow the ISS crew to service and repair EVA hardware, including the MEGA EMU PLSS. EVA hardware, originally certified to be delivered to the ISS by the Space Shuttle would now have to be certified for delivery on the expendable Japanese HTV. Also, since each EVA crewmember requires specific suit sizing components, from custom built EMU gloves to three different sizes of the Hard Upper Torso, the concept of a component sizing “pantry” had to be developed that would allow the maximum number of crewmembers to have specific crew-sizing components while minimizing EVA hardware upmass requirements.

This change in the philosophy of EVA operations concept was deemed so dramatic that the formation of the EVA 2010 Project and Team was crucial to successful transition into the post-Shuttle era. By identifying the differences between ISS EVA operations pre-Shuttle and post-Shuttle the EVA 2010 team was able to set in motion the appropriate project plans. An excerpt from the initial critical assumptions is itemized below:

- Post-2010 ISS EVA rate of 4 scheduled plus 2 contingency EVAs per year
- Soyuz, Progress, ATV and HTV are minimally available for hardware delivery

- All EVA hardware is disposable
- Oxygen and water will be provided by ISS
- 3 ISS crewmembers, all trained for EVA
- Maintain stowage volume within existing allocation on ISS
- Crew specific hardware will launch with crew on Soyuz
- Orbital Replacement Unit capability of EMU will be used
- EMU and EVA Tools will be capable of non-ORU component replacement as needed
- Work within the perimeters of the current EMU system certification (no influx of advanced technology and no major redesign)
- No Crew Exploration Vehicle cargo space available from 2010 until no earlier than 2014

VI. HTV Overview

The HTV is the transfer vehicle designated to transport EVA. The targeted launch of HTV-5 in 2013 is currently being reserved for the EVA Systems hardware, particularly the critical EMU component, the PLSS. Fig. 3 shows the current configuration of the HTV and the associated H-IIB launch vehicle.⁷

The HTV is unique in its capabilities. The HTV is JAXA's first unmanned vehicle specifically designed to transport cargo to the ISS. The HTV can carry up to 6,000kg of cargo. The HTV also has the unique capability of transporting 4500 kg of pressurized cargo and 1500 kg of unpressurized cargo at once.⁵ The general specifications of the HTV are shown in Table 1.

Another unique feature of the HTV is the hatch that opens to the ISS on orbit. It is wide enough to transport large pressurized experiment racks into the ISS. Furthermore, a new

Dimensions	Length: 9.2 m Diameter : 4.4 m
Total mass full loaded	16.5 tons
Launch Vehicle	H-IIB launch Vehicle
Target orbit	Altitude: 350km~460km Inclination: 51.6deg
Cargo capability	6 tons in total
Press.	Up to 5.2 tons 8 ISPR equivalent racks 300kg potable water
Un-press.	Up to 1.5 tons Up to 3 EF payloads Up to 6 Battery ORUs Potential Cargoes
Propulsion system	Four 500N main engine Twenty eight 120N RCS thrusters

Table 1. HTV General Specifications

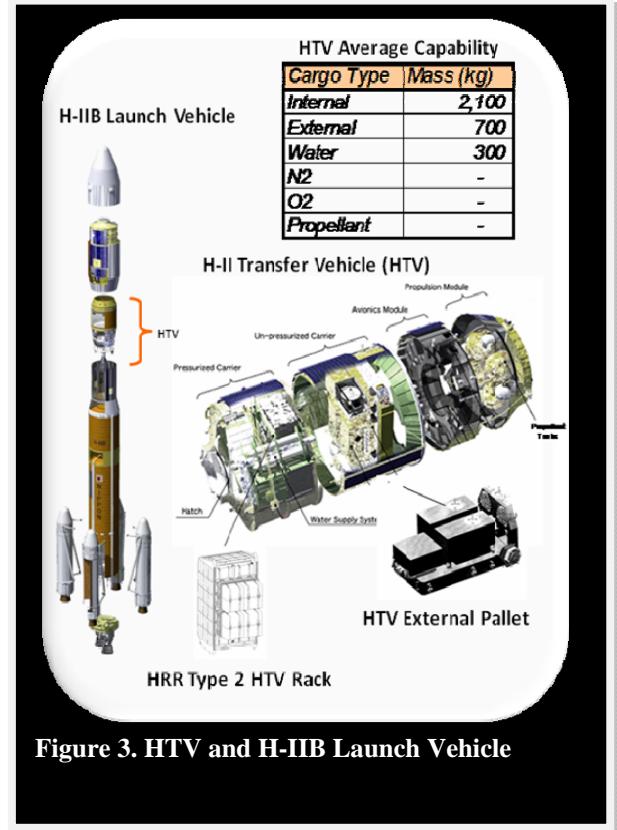


Figure 3. HTV and H-IIB Launch Vehicle

rendezvous/berthing technology uses the ISS robotic arm to dock the HTV to the ISS. HTV-1 in September 2009 was the first docking of this type ever performed on ISS.

The HTV is large enough to accommodate a tour bus. It is approximately four meters across and a little less than ten meters long and consists of three primary components: 1) a propulsion module; 2) an Avionics module; and a logistics carrier. An overview of the HTV system can be seen in Fig. 4.

A. Propulsion Module (PM)

The propulsion module is installed in the rear of the vehicle and consists of propellants necessary to generate propulsion for rendezvous, attitude control, and deorbit. The PM is composed of main engines for orbit changes, a Reaction Control System (RCS) for position control, fuel and oxidizing reagent tanks, and high-pressure air tanks. It is essentially consists of the propellant tanks, pipes, valves, and sensors for thrusting.¹⁰

B. Avionics Module (AM)

The avionics module is installed in the center part of the vehicle. The avionics module includes the navigation, communication, and electrical equipment. Specifically it houses the electronic equipment for guidance, navigation and control, electrical power supply, and telecommunications data processing. It receives commands sent from the ground or the ISS through NASA's Tracking and Data Relay Satellite (TDRS).

C. Logistics Carrier

The HTV logistics carrier stores the supplies to be transported to the ISS. Specifically the Logistics carrier consists of the following:

1) Pressurized Logistic Carrier (PLC)

The PLC provides a shirt sleeve environment for cargo destined for use on ISS. The temperature and pressure are controlled. The PLC is where the critical component of the EMU (PLSS) would be stored. The crew can go onboard and remove the items such as food, clothes, and racks. There are two types of rack bays inside the carrier, one located on the hatch for International Standard Payload Racks or HTV Resupply racks. The second rack bay is located in the rear to accommodate HRRs that will not be transferred into the ISS.

2) Unpressurized Logistics Carrier (ULC)

An ULC can accommodate an Exposed Pallet (EP) as the HTV is transported to the ISS. The EP can carry experiments and orbital replacement units that will be operated external outside ISS. The EP will be removed by the ISS station arm. It will be unloaded and reloaded on to the HTV.

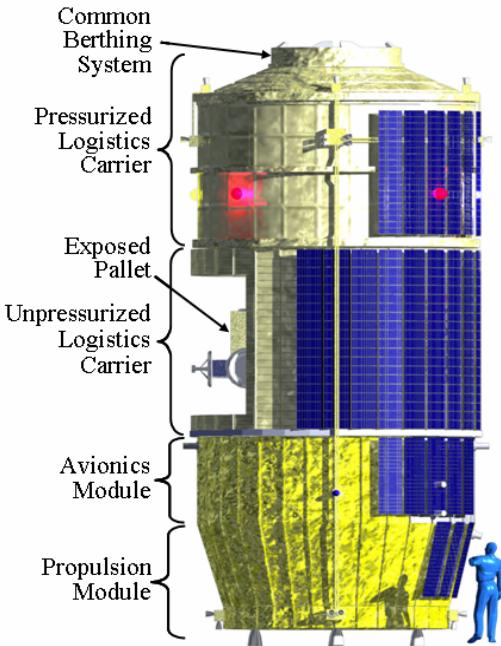


Figure 4. HTV Overview

VII. HTV Launch Operations

The HTV is launched from the Yoshinobu Launch Pad at Tanegashima Space Center (Fig. 5) by the H-IIB launch vehicle. Fig. 6 shows the lift off of the maiden launch of the HTV in Japan in September 2009. Once the HTV has separated from the H-IIB, the HTV is controlled by the guidance and navigation system or Global Positioning System (GPS) until it reaches the ISS. Commands are sent from the ISS or the ground to the HTV through the TDRS. Within 10 meters of the ISS, the robotic arm grapples the HTV and berths it to nadir side of ISS. After attaching to the ISS, the HTV becomes part of the ISS at the PLC portion of the HTV. The crew transfers cargos and supplies from the HTV and replaces it with trash. The HTV undocks from ISS and is destroyed upon reentry. The HTV launch operations scenario is shown in Fig. 7.



Figure 5. Yoshinobu Launch Pad at Tanegashima Space Center



Figure 6. HTV-1 Maiden Launch at liftoff

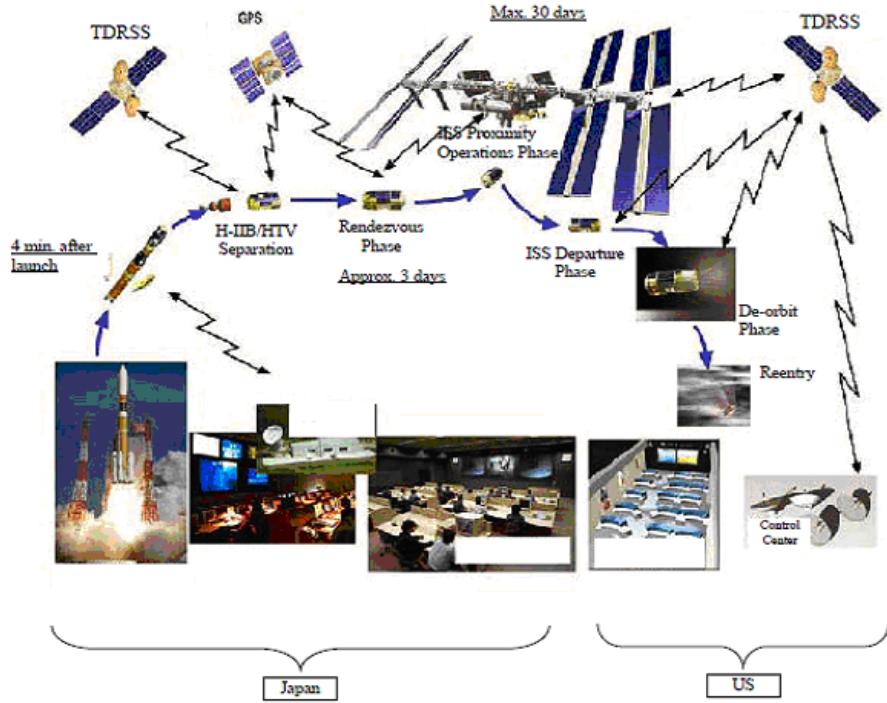


Figure 7. HTV Launch Operations

VIII. The H-II

National Space Development Agency of Japan (NASDA) launched the first H-II on February 3, 1994. The first five H-IIs succeeded. When the last two failed, NASDA embarked upon the H-IIA development.¹¹ The H-IIB was an upgraded design based on research and development that was realized from the H-IIA vehicle. The objective of the upgrade was to improve the reliability of the vehicle by reducing the risk and reducing the overall cost of launch capability. The H-IIB offers a cluster engine design to help increase the thrust capability.⁴ The H-IIB was built to launch the HTV to ISS and to respond to a broader launch capability.¹² The H-IIB vehicle is a two-stage rocket design as shown in Fig. 8. It was developed and manufactured under a unique collaboration between JAXA and Mitsubishi Heavy Industries (MHI). JAXA was responsible for developing cutting-edge technology such as engine clustering, and MHI was responsible for developing the manufacturing technology to fabricate the large-diameter propellant tank.¹³ This clustering was designed as an upgrade to the H-IIA to specifically launch the HTV. The evolution of the H-IIB rocket as compared to its predecessors is shown in Fig. 9 and Table 2.¹⁴

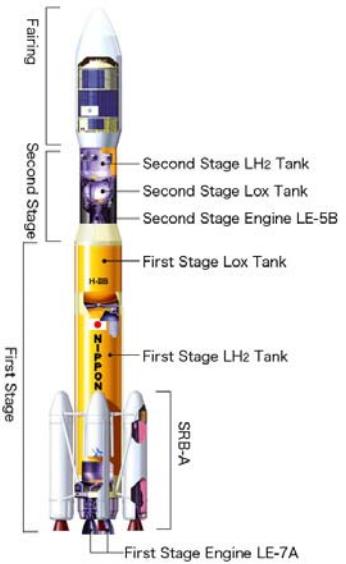


Figure 8. H-IIB Launch Vehicle

Item	H-IIB Launch Vehicle	H-IIA Launch Vehicle 204(Reference)
Length	56m	53m
Mass	531metric tons	445metric tons
First Stage Outside Diameter	5.2m	4m
First Stage Engine	LE-7A 2units	LE-7A × 1unit
Second Stage Outside Diameter	4m	4m
Second Stage Engine	LE-5B	LE-5B
Rocket Booster	SRB-A	SRB-A
Launch Capability (GTO)	8metric tons	6metric tons
Launch Capability (Orbit for HTV)	16.5metric tons	

Table 2. H-IIA and HIIIB Parameters

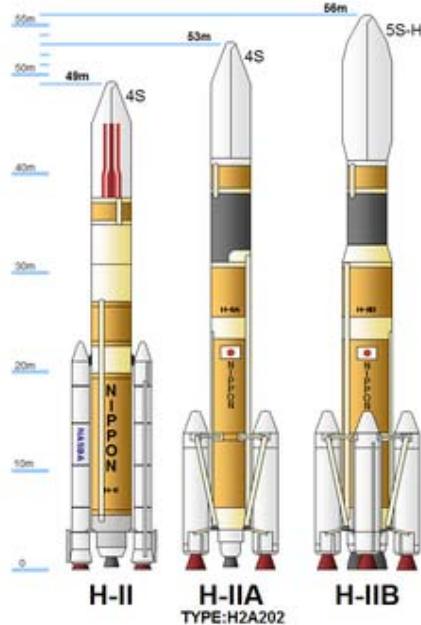


Figure 9: H-II B Compared to the H-II & HIIA

The H-IIB consists of a 5.2 meter diameter (expanded from 4 meters on H-IIA) core first stage, powered by two LE-7A engines (H-IIA only had one) using liquid oxygen (LOX) and liquid hydrogen (LH₂) as propellants and is augmented by four strap-on solid rocket boosters (SRB-A) powered by polybutadiene. The second stage was essentially the same as the H-IIA version, which is powered by a simplified, multi-restartable LE-5B LOX/LH₂ engine. A new 5.1 meter diameter payload fairing is used to store the HTV. Major characteristics of the H-IIB test flight can be found in Appendix A.

In addition to its low Earth orbit (LEO) heavy lifting capability, the more powerful H-IIB rocket can lift up to 8 metric tons to geostationary transfer orbit (GTO). This ability has made the H-IIB the third most capable GTO launch vehicle in the world, after Delta IV Heavy and Ariane 5 ECA.¹³ With this legacy, the EVA community should feel confident that the critical EVA System Hardware can be transported safely and reliably. This paper does not address the potential loads and dynamic implication on the EVA System hardware.

IX. Conclusion

With two successful flights of the HTV and with three more HTV launches ahead, the EVA community moves closer to realizing a successful launch opportunity for the EVA Systems hardware on HTV-5. Although there are several other options that have been identified that can facilitate the challenge of servicing ISS namely the Russian Federal Space Agency's Soyuz and Progress spacecraft, European Space Agency's ATV. With the HTV chosen for the EVA Systems hardware, it is critical that launch operations are well defined and have been successful. There will be a tremendous amount of work to get to 2013 for HTV-5, however the foundation is in place for a successful scenario. This foundation includes a solid EVA ISS operations concept post-Shuttle as well as a proven capability of HTV/H-IIB to accommodate the launch need with proven launch history, a pressurized cargo capability, and the launch capacity. The next couple of years will be exciting, challenging, and reflective as the Space Shuttle retires and the space program migrates to a new approach in maintaining and operating the ISS. At this time there are no plans to bring any of the US Spacesuits back from ISS. Once all the flight certified suits have been delivered on the HTV, the current plan is for the Spacesuit to be disposed of.

Appendix

Appendix A: Major Characteristics (H-IIB Test Flight) and H-IIB Launch Vehicle Launch Capacity

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References

¹Pursuant to the Authorization Act of 2005, NASA provided Congress with the “Human Space Flight Transition Plan,” July 2006.

²Foster, M. A. and Sirko, R. J., “Leveraging Existing Space Assets for Delivery of Cargo to the International Space Station”, *Space 2006*, AIAA 2006-7267, San Jose, California, Sept. 2006.

³Staff writers, “Boeing wins billion dollar NASA extension”, http://www.space-travel.com/reports/Boeing_wins_billion_dollar_NASA_extension_999.html, Space Travel Exploration and Tourism, Washington (AFP), Sept 14, 2010.

⁴HTV-1 Mission Press Kit, Japan Aerospace Exploration Agency, Sept. 2009.

⁵JAXA Overview, H-II Transfer Vehicle (HTV),

http://www.jaxa.jp/projects/rockets/htv/index_e.html?print=true&css=, Retrieved Sept. 2010.

⁶Macias, B., “Cargo Resupply Analysis for the International Space Station, Post Assembly Complete Timeframe”, *38th Aerospace Sciences Meeting & Exhibit*, AIAA 2000-0007, Reno, NV, Jan. 2000.

⁷West, W., Witt, V., and Chullen, C., “NASA, Houston EVA 2010: Preparing for International Space Station EVA Operations Post-Space Shuttle Retirement”, *40th International Conference on Environmental Systems*, AIAA-2010-6130, Barcelona, Spain, July 2010.

⁸Etter, D., “Certify MEGA EMU for Six Year Maintenance Interval,” CR EVA-00920-RO, March 2009.

⁹Sakashita, T., and Kamiya, T., “How the HTV Cargo Vehicle is Fully Stuffed-Cargo Loading Capability Enhancement and Related Issues”, *40th International Conference on Environmental Systems*, AIAA-2010-6046, Barcelona, Spain, July 2010.

¹⁰Kamiya, T., Matsuda, T., Fukatsu, T., Sato, T., Fukuzawa, K., Ohsawa, I., and Mitsuki, H., “HTV Thermal Control Architecture and First Flight Results”, *40th International Conference on Environmental Systems*, AIAA-2010-6221, Barcelona, Spain, July 2010.

¹¹H-IIA Brief Description, NASDA, December 2001 and H-IIB Product Description, NASDA, 2009, http://www.jaxa.jp/projects/rockets/h2b/index_e.html, Retrieved Sept. 2010.

¹²“H-II Launch Vehicle Design Pamphlet”, http://www.jaxa.jp/countdown/h2bf1/index_e.html, Japan Aerospace Exploration Agency Public Affairs Department, Japan, Retrieved Sept. 2010.

¹³Goto, T., “The Next Step in Japan’s Space Development”, http://www.jaxa.jp/projects/rockets/h2b/index_e.html, Retrieved Sept. 2010.

¹⁴“H-IIB Launch Vehicle”, http://www.jaxa.jp/countdown/h2bf1/overview/h2b_e.html, Retrieved Sept. 2010.

Appendix A

Major Characteristics (H-IIB Test Flight)

Length (m)	56.6			
Mass (t)	531 (without payload mass)			
Guidance Method	Inertial Guidance Method			
Item				
	First Stage	Solid Rocket Booster (SRB-A)	Second Stage	Payload Fairing (5S-H)
Height (m)	38	15	11	15
Outside diameter (m)	5.2	2.5	4.0	5.1
Mass (t)	202	306 (for four SRB-As in total)	20	3.2
Propellant mass (t)	177.8	263.8 (for four SRB-As in total)	16.6	-
Thrust (kN) ^{*1}	2,196	9,220	137	-
Combustion time (s)	352	114	499	-
Propellant type	Liquid oxygen/hydrogen	Polybutadiene composite solid propellant	Liquid oxygen/hydrogen	-
Propellant supply system	Turbo pump	-	Turbo pump	-
Impulse to weight ratio (s) ^{*1}	440	283.6	448	-
Attitude control method	Gimbal	Movable nozzle	Gimbal gas jet system	-
Major onboard avionics	Guidance control equipment Telemetry transmitter	-	Guidance control equipment Radar transponder Telemetry transmitter Command destruct system	-

*1 In vacuum. Solid rocket booster's thrust is set to the maximum value.

H-IIB Launch Vehicle Launch Capacity

Orbit	Altitude	Payloads
Geosynchronous Transfer Orbit (GTO)	36,000km	8t
Orbit for HTV (Inclination:51.6 degrees)	350km-460km	16.5t

Reference: http://www.jaxa.jp/countdown/h2bf1/index_e.html